NETWORK-BASED METHOD AND SYSTEM FOR ANALYZING AND DISPLAYING RELIABILITY DATA

BACKGROUND OF THE INVENTION

This invention relates generally to computer network-based systems and more particularly to a network-based method and system for collecting, analyzing, and reporting reliability data.

Superior product and system reliability is achieved when reliability tools are integral parts of development, design, manufacturing, and service processes. Historically quality control efforts have been directed toward minimizing the number of product units that do not meet dimensional and/or performance criteria before leaving the manufacturing plant. This limited approach does not suffice in ascertaining failure modes, to estimate the likely impact of a potential corrective action, or to follow the incidence and nature of product failures over time. It also makes it difficult to provide objectively determined product life expectancy data to prospective customers.

Therefore it would be desirable to provide a system and method to analyze reliability data for facilities running reliability tests to allow users to ascertain overall failure rates, to dissect those overall rates into failure rates for specified failure modes, and to obtain plots and parameters as a function of time. It would further be desirable if the reliability data were accessible at sites remote from the facility to minimize the time and effort necessary to compile and submit such data to a remote site.

BRIEF SUMMARY OF THE INVENTION

The present invention includes a tool that allows the user to record reliability data, obtain unreliability plots, obtain Weibull distribution parameters, create control charts for those parameters over time, and obtain hypothesis tests to ensure reliability has not changed due to process variation. The tool allows users to identify variations that could affect the overall reliability of products through control charts that serve as an early warning for changes in product and system life by plotting shape (β) and scale (η) parameters. The tool also allows users to obtain plots and statistics for specific failure modes that may appear. A system of failure mode codes facilitates filtering of the data.

The tool allows analysis of failure incidence and modes of failure over time, and provides an estimate of the likely impact of an action designed to improve the reliability of a given component of a product. It also provides objectively determined life expectancy data for a product, which confers a marketing advantage. Moreover, users can access the tool over the Internet and have access to reliability data for a plant located anywhere in the world.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a system in accordance with one embodiment of the present invention;

Figure 2 is an expanded version block diagram of an exemplary embodiment of a server architecture of an alternative system;

Figure 3 is a flow diagram of a network-based method for analyzing and displaying reliability data;

Figure 4 is an exemplary embodiment of a Reliability Summary Report page for reporting purposes that includes a plurality of pull down menus to be used when supplying information to the system shown in Figure 3;

Figure 5 is an exemplary embodiment of a report downloaded and displayed by the system shown in Figure 3 as Weibull & Pareto plots when the user has selected the appropriate filters;

Figure 6 is an exemplary embodiment of a report downloaded and displayed by the server system shown in Figure 3 as control charts when the user has selected the appropriate filters;

Figure 7 is an exemplary embodiment of a user interface for data entry downloaded and displayed by the server system (shown in Figure 3) for the user to select the reliability instance (characteristic test) of the data to be entered;

Figure 8 is an exemplary embodiment of a user interface downloaded and displayed by the server system (shown in Figure 3) for the user to enter the data points;

Figure 9 is an exemplary embodiment of a Reliability CTQ Setup page;

Figure 10 shows a plot of F, the failure cumulative probability or rank, vs. T, the failure time or cycles with confidence bounds;

Figure 11 shows a plot of F, the failure cumulative probability or rank, vs. T, the failure time or cycles with confidence bounds illustrating the concept of percentiles or $L_{X\%}$;

Figure 12 shows control charts of beta, the shape of the Weibull distribution, vs. fiscal weeks (FW).

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a block diagram of a system 10 in accordance with one embodiment of the present invention. System 10 includes a server sub-system 12, sometimes referred to herein as server 12, and a plurality of user devices 14 connected to server 12. In one embodiment, devices 14 are computers including a web browser, and server 12 is accessible to devices 14 via a network such as an intranet or the

Internet. In an alternative embodiment, devices 14 are servers for a network of customer devices.

Devices 14 are interconnected to the network, such as a local area network (LAN) or a wide area network (WAN), through many interfaces including dial-in-connections, cable modems and high-speed ISDN lines. Alternatively, devices 14 are any device capable of interconnecting to a network including a network-based phone or other network-based connectable equipment. Server 12 includes a database server 16 connected to a centralized database 18 containing reliability information. In one embodiment, centralized database 18 is stored on database server 16 and can be accessed by potential users at one of user devices 14 by logging onto server sub-system 12 through one of user devices 14. In an alternative embodiment centralized database 18 is stored remotely from server 12.

Figure 2 is an expanded version block diagram of an exemplary embodiment of a server architecture of a system 22. System 22 includes server sub-system 12 and user devices 14. Server sub-system 12 includes database server 16, an application server 24, a web server 26, a fax server 28, a directory server 30, and a mail server 32. A disk storage unit 34 is coupled to database server 16 and directory server 30. Servers 16, 24, 26, 28, 30, and 32 are coupled in a local area network (LAN) 36. In addition, a system administrator workstation 38, a user workstation 40, and a supervisor workstation 42 are coupled to LAN 36. Alternatively, workstations 38, 40, and 42 are coupled to LAN 36 via an Internet link or are connected through an intranet.

Each workstation 38, 40, and 42 is a personal computer having a web browser. Although the functions performed at the workstations typically are illustrated as being performed at respective workstations 38, 40, and 42, such functions can be performed at one of many personal computers coupled to LAN 36. Workstations 38, 40, and 42 are illustrated as being associated with separate functions only to facilitate an understanding of the different types of functions that can be performed by individuals having access to LAN 36.

In another embodiment, server sub-system 12 is configured to be communicatively coupled to various individuals or employees 44 and to third parties, e.g., users, 46 via an ISP Internet connection 48. The communication in the exemplary embodiment is illustrated as being performed via the Internet, however, any other wide area network (WAN) type communication can be used in other embodiments, i.e., the systems and processes are not limited to being practiced via the Internet. In addition, and rather than a WAN 50, local area network 36 could be used in place of WAN 50.

In the exemplary embodiment, any employee 44 or user 46 having a workstation 54 can access server sub-system 12. One of user devices 14 includes a workstation 54 located at a remote location. Workstations 54 are personal computers having a web browser. Also, workstations 54 are configured to communicate with server sub-system 12. Furthermore, fax server 28 communicates with employees 44 and users 46 located outside the business entity and any of the remotely located user systems, including a user system 56 via a telephone link. Fax server 28 is configured to communicate with other workstations 38, 40, and 42 as well.

Figure 3 is a flow diagram 70 for a network-based method for analyzing and displaying reliability data. In one embodiment, a system administrator establishes 71 the reliability instances or test specifications. The user inputs information into a device (such as device 14 shown in Figure 1) that transmits the information to a server (such as server 12 shown in Figure 1). The data is received 72 through specified filters 73 via a graphical user interface, as will be described in greater detail below.

Server 12 performs 74 statistical tests on the received reliability information based on the filters (pull downs) selected. In one embodiment, the statistical tests are stored on server 12. In an alternative embodiment, the statistical tests are stored on a computer remote from server 12.

System 10 then generates 76 a report in accordance with the preferences selected by the user. Server 12 then displays 78 the generated report to user device 14 so that the user can view the report.

Figure 4 is an exemplary embodiment of a Reliability Summary Report page, as depicted in screen shot 80, which includes a plurality of pull down menus to be used when supplying information to system 10 (shown in Figure 1). Screen shot 80 includes a Plant pull down menu 82, a Product Line pull down menu 84, a Catalog No. pull down menu 86, a Type of Test pull down menu 88, a Failure Mode pull down menu 90, a Specification #1 display area 92, and a Subgroups In pull down menu 94. Screen shot 80 also includes a Data Set 1 area 96, which includes pull down menus for specifying a data period and display fields for indicating a total number of units, a number of units failed, a number of units passed, a number of failure modes, a beta parameter (defined below), an eta parameter (defined below), an r^2 parameter (defined below) and an L_{10} parameter (defined below). Screen shot 80 further includes a Data Set 2 area 98, which includes pull down menus for specifying a data period and display fields for indicating a total number of units, a number of units failed, a number of units passed, a number of failure modes, a beta parameter (defined below), an eta parameter (defined below), an r^2 parameter (defined below) and an L_{10} parameter (defined below). Screen shot 80 still further includes a Confidence Interval selection area 100, a Control Charts radio button 102, a New Test radio button 104, a New Data radio button 106, and an Exit radio button 108. Selection of Control Charts radio button 102 replaces plots with control charts, as defined below, while selection of New Test radio button 104 takes the user to a data collection window with the current setup. Selection to New Data radio button 106 takes the user to a data collection window with a current setup, while selection of Exit radio button 108 allows the user to exit system 10 (shown in Figure 1).

Figure 5 is an exemplary embodiment of a Reliability Interface results page, as depicted in screen shot 120, in which display area 122 and Confidence Interval selection area 124 show an exemplary choice of variables corresponding to items 82 through 100 in Figure 4. Screen shot 120 also includes a Weibull Cumulative Probability Function plot 126, and a Pareto of Failure Modes display area 128, as well as a set of radio buttons 130 that correspond to radio buttons 102,104, 106 and 108 in Figure 4. The Weibull Plot overlays the two data sets plot for comparison purposes. Also, the Failure Modes Pareto colors the failure mode(s) under study differently.

Figure 6 is an exemplary embodiment of a second Reliability Interface results page, as depicted in screen shot 140, in which display area 142 and Confidence Interval selection area 144 show another exemplary choice of variables corresponding to items 82 through 100 in Figure 4. Screen shot 140 also includes a Control Chart for Beta plot 146, and a Control Chart for Eta plot 148, as well as a set of radio buttons 150 that correspond to radio buttons 102,104, 106 and 108 in Figure 4.

Figure 7 is an exemplary embodiment of a Reliability Data Collection page, as depicted in a screen shot 160, which includes a set of pull down menus 162 for specifying a plant, a product line, a catalog number, a type of test, a number of units, a tester, and any specifications. Screen shot 160 also includes a pull down menu 164 for specifying a type of test, and a data table 166 that displays the date, identification number, failure time, failed/pass, and a failure mode columns. Screen shot 160 also includes a Generate Report radio button 168, a New Test radio button 170, a New CTQ radio button 172, a Save radio button 174, and an Exit radio button 176. Selection of Generate Report radio button 168 causes system 10 (shown in Figure 1) to display a report window, while selection of New Test radio button 170 restores this page with all default values. Selection of New CTQ radio button 172 causes system 10 to display a CTQ setup window (described below), while selection of Save radio button 174 saves input data and calculates parameters. Selection of Exit radio button 176 causes the user to exit system 10.

Figure 8 is an exemplary embodiment of a second Reliability Data Collection page, as depicted a screen shot 180, which includes a set of pull down menus 182 that show an exemplary choice of a plant, a product line, a catalog number, a type of test, a number of units, a tester, and a specification. Screen shot 180 also includes a Reliability Data Collector area 184 that appears to all-out data entry when all required fields have been selected. Selection of an Enter button in area 184 causes any new data to appear in data table 186, which corresponds to report area 166 in Figure 7. Screen shot 180 also includes a set 188 of buttons that allow a choice of Generate Report, New Test, New CTQ, Save, and Exit options.

Figure 9 is an exemplary embodiment of a second Reliability CTQ Setup page, as depicted in a screen shot 190, which includes a set of pull down menus 192 that show an exemplary choice of a plant, a product line, a catalog number, a type of test, a number of units, and a tester. Screen shot 190 facilitates creation of the new test description of a reliability instance. Screen shot 190 also includes a Specifications area 194 that includes a set of Specification text boxes for specifying an L_{10} , a number of units, and a % Confidence Level for each of Specification #1, Specifications #2, and Specifications #3. Screen shot 190 also includes a plot 196 of Unreliability vs. Time or Cycles, to illustrate the concept of a reliability specification as well as a set 198 of radio buttons corresponding to radio buttons 168, 170, 172, 174, and 176 shown in Figure 7.

The mathematical background of the statistical analysis of the data is described below. This method uses the Weibull function as the assumed distribution because of its flexibility in assuming various distribution profiles.

The life data for probability plotting has two axes: T, the actual failure time or cycles, and F, the failure cumulative probability or rank. Of the several methods of calculating F, median rank has been determined to be the best for skewed distributions. Medium rank has been used in the exemplary embodiment because: 1) Weibull distributions could be symmetrical or non-symmetrical; and 2) If the life data are normal (wearout failures) the mean, midpoint and the median should all be the same. The Weibull cumulative density function is given by:

$$F(t) = 1 - e^{-\left(\frac{t}{\eta}\right)^{\beta}}$$

where β and η represent the shape and scale parameters of the Weibull distribution respectively. Beta values less than one correspond to early failures, while those of about 2 or greater represent wearout failures. Beta values near unity indicate random failures that can be used to estimate useful life. Eta represents the point at which 1/e of the units fail that corresponds to the midlife of a unit. The T and F axes are transferred to the linear form of the Weibull expression through use of

$$\ln(t) = \frac{1}{\beta}\ln(-\ln(1-F(t))) + \ln(\eta),$$

which is in the form of Y=bX+u. With the data transformed, the best linear unbiased estimate (abbreviated BLUE) can be obtained. In the exemplary embodiment, the method of least squares in X has been used. The method of least squares provides the lowest variance of all possible unbiased estimators of the regression parameters b and u. b and u are estimates of β and η by the relation shown in the following equations.

$$SS_x = \sum_{i=1}^{n}(x_i - \bar{x})^2 \qquad b = \frac{SS_{xy}}{SS_x}$$

$$SS_{xy} = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) \qquad u = \bar{y} - b\bar{x}$$

$$SS_y = \sum_{i=1}^{n}(y_i - \bar{y})^2 \qquad r^2 = \frac{b * SS_{XY}}{SS_Y}$$

As a means to verify accuracy of the model's prediction, the coefficient of determination (r^2) is interpreted as the proportion of the variation in Y that is explained by the regression of Y with X. With the linear estimate, transforming back to Weibull's original form, the percentiles (T) and probabilities (F) can be calculated.

The time by when 10% of the units are expected to fail or L_{10} is another statistic of interest in this module. This time is the Reliability Critical-to-Quality (CTQ) criterion for any given product. The L_{10} is estimated with a certain confidence level (CL). For example, by substituting 0.10 as F in the F(T) equation from the Weibull model, the L_{10} at 50% confidence level can be calculated since the line represents the Median (or 50%) Rank. In most cases a 90% confidence level is used. The 90 confidence level can be obtained using the confidence bounds. A non-parametric method is discussed below.

The confidence intervals represent the range for the expected variation in F at any given T and vice versa. This range includes limits that contain a specified percentage of variation, for example a 90% confidence interval contains 90% of the variation. The line obtained from the regression represents median rank and therefore 50% of the variation at each side. Consequently, the upper and lower limits or bounds

of this 90% confidence interval are called the α and $1-\alpha$ confidence bounds where $2\alpha-1$ equals the specified confidence interval. Figure 10 and Figure 11 show how these bounds are used to make estimates at α and $1-\alpha$ level. These limits are non-parametric curves that connect the α and $1-\alpha$ ranks (R_α and $R_{1-\alpha}$) calculated for each failure **k** from a subgroup of size n as follows.

$$\alpha = \sum_{k=j}^{n} \binom{n}{k} R_{\alpha\%} \left(1 - R_{\alpha\%} \right)^{n-k} \quad \text{(for lower rank)}$$

and

$$1-\alpha = \sum_{k=j}^{n} \binom{n}{k} R_{1-\alpha\%} \left(1 - R_{1-\alpha\%} \right)^{n-k} \quad \text{(for upper rank)}$$

where $\binom{n}{k} = \frac{n!}{k!(n-k)!}$.

These ranks are plotted vertically along the median ranks of every failure point for the predicted time or cycles to failure. This means that the median rank value for every failure point is substituted in the F(T) expression as F, then the upper and lower ranks are plotted vertically along the $t = T(F)$, as shown in Figure 10 and Figure 11. With these ranks calculated, any percentile (T) can be obtained at the confidence level of the corresponding bounds where the ranks lies by interpolation/extrapolation methods. For example, if the L_{10} 10% is desired at 95% confidence level (CL), using the 95% confidence bound (a 90% confidence interval) an interpolation would have to be performed between the two data points with $R_{95\%}$ above and below 10%.

Figure 12 shows control charts of beta, the shape of the Weibull distribution, vs. fiscal weeks (FW). A control chart is a graphical display of the variation of any targeted statistic during an industrial process through time. In the exemplary embodiment, the β and η parameters have been monitored since an instability of these values provides an early alarm of variation in the processes that affect reliability of the product or system. For both parameters the control chart plots

four quantities, historical parameter (β, η), upper control bound (UCB), lower control bound (LCB), and subgroup parameters.

The user selects a grouping period that determines the number of points used in every plot. The grouping periods are by one of fiscal week, month, quarter and year. For instance, if the user selects that the data are grouped by fiscal weeks, a subgroup will contain all data points recorded between Monday and Sunday of that week. The control chart plots up to 12 subgroups back in data. The subgroup parameters are those calculated through use of the data contained in the grouping period specified by the user. The historic parameters are those calculated through use of the data contained between the period when the report is requested and the preceding twelve months, if the data are available. The control bounds are calculated through use of the confidence intervals for the parameters β and η. These are calculated as follows:

$$\beta_L = 1 / (D * \exp(1.049K_\gamma / n^{1/2})) \qquad \text{(lower beta limit)}$$

and

$$\beta_U = 1 / (D / \exp(1.049K_\gamma / n^{1/2})) \qquad \text{(upper beta limit)}$$

$$\eta_L = \exp (L - 1.081K_\gamma (D/n^{1/2})) \qquad \text{(lower eta limit)}$$

and

$$\eta_U = \exp (L + 1.081K_\gamma (D/n^{1/2})) \qquad \text{(upper eta limit)}$$

where K_γ = the $[100(1+\gamma)/2]$th standard normal percentile

$D = 0.7797$ * standard deviation of the subgroup

L = subgroup mean + $0.5772*D$

n = subgroup size

Any point falling out of those limits is an indicator that this point is from a different population than the collective group with a least a γ% confidence. These control bounds are to be recalculated after four new subgroups of data have been recorded to reduce sensitivity of the limits.

In use, system 10 (shown in Figure 1) provides the user with a way of analyzing and displaying reliability data. This reliability module establishes a data collection system for manufacturing plants and facilities performing reliability testing. It provides easy data entry windows and complete reports that includes Weibull plots, failure mode Pareto plots, control charts for distribution parameters, and other life predictors.

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.